Renewable and Sustainable Energy Reviews 16 (2012) 2973–2979

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Application of low waste technologies for design and construction: A case study in Hong Kong

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A R T I C L E I N F O

Article history:
Received 17 August 2011
Received in revised form 7 February 2012
Accepted 10 February 2012
Available online 22 March 2012

Keywords:
Low waste technology (LWT)
Design and construction
Barriers
Construction waste management
Hong Kong

A B S T R A C T

Environmental impacts from construction waste have been increasingly becoming a major issue in urban management, particularly in the densely populated regions, such as Hong Kong. This paper presents the current practices of using low waste technologies (LWT) for design and construction in terms of their implementation level and barriers in application on site. Through two practical cases and the semi-structured interviews, the research presents discussions on of the major low waste technologies that have been adopted and the implementation extent of these LWTs in both design and construction stages. The study provides recommendations for improving the use of LWT, including the corresponding technology instruments and the government may develop and implement. The research result can help understand the current situation in applying LWT in design and construction and the findings are expected to assist the decision makers to formulate a set of design and technology toolkit for improving construction waste management.

Contents

1. Introduction

The world is facing severe challenges of environmental problems in many disciplines. “Environment is the surrounding in which an organization operates, mainly including air, water, land, natural resources, flora, fauna, humans, and their interrelations” [1]. Poor living environment is caused by the poor environmental performance that is the result of various poorly controlled activities. Existing researches comprehend that construction activity is a major contributor to the poor environmental performance [2–4]. Comprehensive examinations of the negative effects in construction activities on the external environment have been given by many previous studies [5–9]. These effects typically include land consumption, land deterioration, resource depletion, waste generation

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doi:10.1016/j.rser.2012.02.020

and various forms of pollution [7]. One major contributor to these negative environmental effects is the construction activities [3,4], as Ofori opined that many natural areas are irreversibly damaged by construction activities, which alter their ecological integrity [5].

The realization of the significant impacts from construction activities on the environment has led to the development of various management approaches for construction participants to implement in order to improve their environmental performance. For example, ISO 14000 series are introduced as part of the overall management system to improve environmental performance across all types of businesses including construction. ISO 14000 series provide guidance on organizational structure, planning, activities, responsibilities, procedures, and resources for developing and implementing environmental policy [10–12]. In line with these developments, waste management in construction activities has been promoted as the major approach aiming to protect the environment.

In Hong Kong, over 80% of construction waste is inert and for public fill. In the past, disposal of public fills and construction waste at sorting facilities or landfills has been the major approach for construction waste management in Hong Kong [13]. In 2009, the mixed construction waste accounts for about 20% of the total waste intake at the three existing landfills. However, both reclamation sites and landfill space are expected to run out in the next few years in Hong Kong. The public fill capacity will be depleted in the near future [14], thus there is an urgent need to find out a sustainable approach to manage waste particularly that generated from construction activities. It is appreciated that the reclamation can no longer be relied on as a main approach to accept the inert construction waste. In this context, alternative construction waste management approaches were identified, such as recycling of concrete waste, use of hybrid concrete construction, and prefabrication of the concrete lump from demolished structures [15,16]. Other proactive approaches have also been developed for avoiding or reducing the generation of construction waste from the construction activities. The Construction Industry Research and Information Association of UK have introduced low waste technologies (LWT) [6]. And Poon et al. investigated the applications of these LWTs by comparing the adoption of LWTs in public and private housing projects in Hong Kong [17]. Poon et al. further revealed that the construction sectors have seldom used LWTs in Hong Kong [17]. This inspires this research team to look at how much LWTs are used, what barriers encountered in application, and in what ways the LWTs help reducing the wastes in construction activities, with referring to Hong Kong construction industry. This understanding leads to provide an efficient waste management toolkit for guiding construction waste management practice.

2. Current construction waste management practices in Hong Kong

This section is to highlight construction waste management practices in Hong Kong. The examination is focused on the construction activities that generate wastes and the major measures of construction waste management.

It is widely appreciated that construction generates the most pollution by comparing with other industries. The major environmental impacts from construction activities are typically classified as air pollution, water pollution, waste pollution and noise pollution [18,19]. Environmental pollution generated from construction industry particularly in these densely populated cities such as Hong Kong is indisputable. According to the study by Clements, the environmental effects of construction industry including (i) energy consumption; (ii) dust and gas emission; (iii) noise distribution; (iv) waste generated; (v) water discharge; (vi) use of water resources; (vii) unnecessary building consumption; (viii) pollution by building materials; (ix) land use; and (x) use of natural resources [10].

There are various definitions and descriptions about construction waste. In a typical definition by the Environmental Protection Department of Hong Kong, construction waste is anything generated as a result of construction activity and then abandoned, regardless of whether it has been processed or stockpiled. It comprises surplus materials from site clearance, excavation, construction, refurbishment, renovation, demolition and road works [18]. In Hong Kong construction practice, the construction wastes are broadly classified into Type I and Type II according to the level of the inclusion of inert wastes. Inert waste materials are described as soil or mud, concrete, reinforced concrete, asphalt, brick or sand, cement plaster or mortar, aggregate, and rock or rubble. Type I construction waste is defined as containing no more than 20% by volume, or 30% by weight, of inert materials. Type II waste consists of more than 20% by volume, or 30% by weight, of inert material. Therefore, type II waste is normally used for site formation or public filling areas. According to the report by Hong Kong Civil Engineering Department [20], about 87% construction wastes were delivered to public fill receptor sites, temporary fill banks and quarries and the remaining 13% being construction and demolition wastes were disposed of at landfills in 2003. There are many proactive waste management measures adopted in construction practice in Hong Kong. At the government level, there are various policies introduced to manage construction waste, including waste disposal ordinance, green manager scheme, waste reduction/management plan, concrete recycling plant and public landfill charging scheme [13,21].

At the industry level, there are also many approaches implemented. In particular, the measures adopted to handle different types of construction waste in the construction phase are highlighted in the following Table 1 [22].

The data in Table 1 indicate that appropriate waste handling measures can be identified for application in the process of handling the three different types of construction waste during the construction phase. For example, the construction hazardous materials can be held safely without loss or leakage by registered contractors or any licensed companies. The waste disposal permits must be obtained from the appropriate authorities for specific category of waste in accordance with the relevant regulations. It is also requested for the appropriate authorities or contractors to keep records of the quantities of construction waste generated. The recycled and disposed construction wastes must be recorded as well.

3. Research method

The research was conducted using three major approaches which includes content analysis (literature review and existing reports), case-study and semi-structured face-to-face interviews with on-site construction project managers. Content analysis is adopted to investigate the optional list of low waste technologies (LWTs) for design and construction, which can help participants to implement waste management strategies. A series of interviews were conducted to engage in-depth understandings on the implementation of LWTs. Two case studies are employed to demonstrate the extent that these LWTs are applied in practice. The research team conducted the two case studies with the assistance of the Hong Kong Housing Authority.

4. Content analysis: low waste technologies (LWTs) for design and construction

4.1. Search strategy and identification procedures of LWTs

Firstly, literature search was conducted by using EI Complex (1990–2011) and Web of Science databases (WOS) (1990–2011).

Table 1
The waste management measures in the construction phase in Hong Kong.

Waste type	Waste handing measures (re-used on site)	Waste disposal measures (on site for reclamation and road base)
Construction and demolition material	If off-site disposal required, separate into: C&D waste Public fill: concrete and rubble	Landfill Public filling area or reclamation
Construction chemical wastes	Recycle on-site or by licensed companies Stored on-site or by licensed companies	Chemical waste treatment facility
Construction hazardous materials	For example, the asbestos, Provide appropriate on-site temporary storage facility; Remove off-site waste by registered contractors	Landfill
Construction labour force waste	Provide on-site refuse collection facilities Main sewerage or septic tank	Refuse station for compaction and containerization and then to landfill; Private hygiene company

Table 2
Summary of low waste technologies (LWTs) for design and construction.

Code	LWTs	Key references
T_1	Design for thinner internal walls and floor slabs	[17,15]
T_2	Waste sorting/segregation technologies	[24–28]
T_3	Design for reducing foundation size	[28–30]
T_4	Design for reusing excavated spoils as back-fill material to balance cut and fill	[31]
T_5	Modular building designs and prefabricated components	[17,28,32,33]
T_6	Reuse technology for construction waste (i.e., bricks and tiles)	[34–36]
T_7	Design for recycled materials such as recycled aggregates and asphalt	[23,32,36]
T_8	Deconstruction or sequential demolition technology	[37]
T_9	Use of large panel formwork	[38–41]
T_{10}	Design for hanging cradles	[17,42]

These two search databases are considered as comprehensive bibliographic database of engineering research available, which covers a large quantity of topics, disciplines and abstracts of waste management technologies and strategies. The literature review is done by selecting the two keywords "design technology to reduce construction waste", "low waste generation technologies for buildings", which are used together with the logical operator "or". The total number of articles retrieved is 55. Obviously, there are a lot of redundant items, which are eliminated by using two exclusion criteria: (1) documents about indirect topics of waste management technologies for construction industry; (2) documents address waste management technologies that are non-relevant to design of buildings. Using the above methods, data from included papers were extracted and recorded independently. Finally, 25 papers were chosen as our initial article database. Secondly, for all of those 25 articles, only those viable low waste technologies for building design that have been mentioned in more than one article by the number of citations will be selected as candidate indicators for low waste technologies. For example, "hanging cradles" have been mentioned in Poon et al. [17] and Roper [42], which is therefore included in the optional indicators. Using this approach, a total of 10 major LWTs were incorporated into a checklist, as shown in Table 2 [17,15,24–42].

5. Case study and semi-structured interviews

Case studies are used in this section to investigate the extent of implementation of LWTs and major barriers to their implementations in practice. Discussions are also conducted on how these methods and technologies can help lower waste generation. The data used for this analysis are collected from two practical cases. The two cases are considered representative projects in Hong Kong. Case I belongs to public infrastructure projects, which will be built for government administration office. Case II is the public housing projects, which will bring larger impacts to the construction of residential projects in Hong Kong. If these two exemplar projects have implemented LWTs, it is expected that many other construction projects could apply these low waste buildings technologies in practice.

5.1. Participants

A total of 15 key informants have participated in this study. They were invited from the two construction project teams in Hong Kong. These two projects differed on several counts, including: the building purpose, contractors in charge, the characteristics of design and applications of building technologies. The participants are ranged from 33 to 55, including male and female members. They are selected by the following two major criteria: (1) holding relevant experiences for more than 5 years; (2) knowing the practical operation of on-site building technologies.

5.2. The interview

Participants were scheduled for an interview time and meeting place first. Each of the interviewees was informed about the purpose of the interview was to collect the information on: (1) what is the extent of implementation of LWTs (e.g., how much level will each of the optional LWTs); (2) what are the major barriers to the practical implementation. The interview discussions have been asked to be anonymous and confidential; however, the dialogues were recorded by the authors. Interviewees were firstly asked to nominate the LWTs adopted in the construction project. Using a pre-designed exemplification framework by the research team, the interview questions were further designed to focus on the implementation of these nominated LWTs, by describing and quantifying the implementation level of them. The interview format was composed of three open-ended questions, which are shown as follows:

(1) What are the major LWTs adopted in your construction project?
(2) What are the major factors and characteristics for the exemplification on the implementation level of LWTs in each of the planning, construction and operation stage?

Table 3
Major factors for the exemplification on the implementation level of LWTs.

Area	Levels	Characteristics
Planning and control of the processes	☼	Scarce structure of process planning and control on the adoption of LWTs. Time schedules are not definite, unclear responsibilities and management has poor control of the process.
	☼☼	A clear holistic structure of the project processes by using the LWTs. All participants respect the dates and schedule.
	☼☼☼	Developed planning in early phases of projects where key participants collaborate to contribute to the proactive implementation of LWTs.
	☼☼☼☼	Clear gates between sub-processes where certain tasks on LWCTs must be fulfilled.
	☼☼☼☼☼	Planning and control systems supported by advanced ICT-tools. Performance measures and feedback on the progress of implementing LWTs is conducted.
Construction process	☼	No clear-cut regulation when the LWTs are implemented on site.
	☼☼	Simple regulations of the LWTs are designed and posted on site.
	☼☼☼	A systematic handbook for implementing the LWTs is given to all the participants in the construction activities.
	☼☼☼☼	A one day workshop on the introduction of the systematic handbook for implementing the LWTs is conducted prior to the launch of the construction project.
	☼☼☼☼☼	The whole construction progress of implementing the LWTs on site will be supported by IT-tools, which will facilitate the whole process.
Facility Operation & Maintenance	☼	No clear-cut regulation on regulating the LWTs
	☼☼	Simple regulation on regulating the LWTs is designed. Examples are attached.
	☼☼☼	A clear-cut regulation and introduction to the maintenance of the LWTs take effect after the completion of projects.
	☼☼☼☼	A regular checking system is set up to monitor the LWTs
	☼☼☼☼☼	The regular checking system to monitor the LWTs is supported by IT-tools and some staffs are responsible to check the implementation timely.

Note: ☼ = 1, the implementation level is lowest; ☼☼ = 2, the implementation level is relatively low; ☼☼☼ = 3, the implementation level is middle; ☼☼☼☼ = 4, the implementation level is relatively high; ☼☼☼☼☼ = 5, the implementation level is highest.

(3) What are the major barriers to the implementation of LWTs in Hong Kong construction projects?

These interview discussions lasted from 20 min to 1 h and the average interview lasted around 30 min. By engaging the discussions with these key informants, a comparative analysis on different implementation of LWTs is carried out. After analyzing all these interview session discussions, a list of optional LWTs for each of the construction projects is obtained; also the details about the two cases are addressed as follows:

5.3. Case 1: Office building project: the Tamar Development Project

The Tamar Development Project covers design and construction of a Central Government Complex, the Legislative Council Complex, an open space and two elevated walkways, in Tamar, Central, Hong Kong. The total site area is around 42,000 m^2 and the total gross construction floor area is around 129,160 m^2. The launch of construction work of the Tamar Development Project was in February 2008, accomplished with several cornerstones such as design development and superstructure works. The project is generally considered on schedule and is expected to be completed in the end of 2011. The major contractor, the Gammon – Hip Hing Joint Venture, has been implementing the construction contract with the value of HK$4.94billion. In line with the overall principle of green development plan of the project, the contractor has showcased a series of low waste construction design and technologies at the Tamar Development Project.

Spotlight on the LWTs in this case study (summarized from the interview report by the authors):

- Use of large panel of durable/reusable system formwork (T_9).
- Reuse of treated contaminated soil as filling material (T_6).
- Reuse of about 77,300 m^3 surplus excavated inert construction waste (about 26% of total anticipated construction wastes) in other construction sites, therefore, at the same time reducing the burden at the public fills (T_6).
- Use of hanging cradles (T_{10}).

5.4. Case 2: Residential Building project: Asia Construction of Housing Blocks under Home Ownership Scheme, Housing Department, HKSAR

This Housing Blocks project is implemented to assist lower-income families to acquire home ownership by introducing the Home Ownership Scheme (HOS). The information about this housing project was collected from a series of interview discussions with the key informants participating in the C&D waste management of the project and supplemented by the online survey report. The project client was the Hong Kong Housing department, and the projects investigated in this study are jointly developed by the Hong Kong Housing Authority and the Chevalier Group.

Spotlight on the LWTs:

- Special design for reusing excavated spoils as back-fill material to balance cut and fill (T_4).
- Adoption of precast facades, staircases and semi-precast floor slabs (T_{5-1}).
- Use of Modular building designs and prefabricated components (i.e., prefabricated door-sets, metal security gates and cooking benches) (T_{5-2}).
- Use of precast and prefabricated external works items such as planters and street furniture (T_{5-3}).
- Use of recycled construction materials (i.e., pulverized fuel ash in cement) (T_7).
- Use of metal moulds for precast items (T_{5-4}).
- Use of metal large panel formwork and steel table formwork (T_9).
- Use of hanging cradles (T_{10}).
- Installation of thinner panel walls in lieu of block work (T_1).

Table 4
Comparison on the implementation level of LWTs in the two cases.

	Planning and control of the processes	Construction process	Facility Operation & Maintenance
Case I:	T_9: ☼☼☼☼	T_9: ☼☼☼☼ T_{10}: ☼☼☼☼	T_6: ☼☼☼
Case II:	T_{5-1}: ☼☼☼ ; T_{5-2}: ☼☼☼☼ ; T_{5-3}: ☼☼☼ ; T_{5-4}: ☼☼☼☼ ; T_9: ☼☼☼☼ T_1: ☼☼☼☼	T_{5-1}: ☼☼ ; T_{5-2}: ☼☼ ; T_{5-3}: ☼☼ ; T_{5-4}: ☼☼ ; T_7: ☼☼☼ ; T_1: ☼☼ T_{10}: ☼☼☼☼ T_9: ☼☼☼☼	T_4: ☼ ; T_1: ☼

6. Results and discussion

Besides the LWTs mentioned above, there are also other alternative measures that have been applied in the case study projects. According to the semi-structured questionnaire designed for the interview discussion with the key informants, the major implementation level of the LWTs can be obtained. The results are assisted by an exemplification framework, and the implementation level for LWTs is therefore being identified (see Table 3). By comparing the two cases, the result can be shown in Table 4.

According to the information in Table 4, the following results can be drawn:

The practices show that significant differences exist in applying LWTs in the planning and control of the processes, construction process and facility operation & maintenance stage. Several LWTs such as the use of large panel formwork (T_9) and the use of hanging cradles (T_{10}) have been implemented in both of the cases. The large panel formwork is a system whereby prefabricated formwork is much larger than the traditional timber formwork, and can repetitively be erected, stuck and re-erected [17]. This kind of formwork design is specified for the construction of load bearing walls of typical floors in high rise public housing of the Hong Kong Housing Authority, which is echoed with the Case II in our study. According to the discussions over the Case II, most of the housing blocks under the Home Ownership Scheme (HOS) in Hong Kong are belong to high-rise buildings. The structure is very complex, either in terms of scale, architectural or structural design, sophisticated building services or other facilities requirements. In this context, the design and use of the large panel formwork system is crucial to the reduction of wastes and overall success of a project. It can therefore be summarized that the implementation level in the two cases is very high.

Another type of LWT that can be found in the two cases is the use of hanging cradles, which are used as working platforms to apply external finishes of the buildings. This is echoed with the discussion from Case I, indicating that most of the traditional buildings in the past were applied with bamboo scaffolding. The traditional hanging bamboo scaffoldings usually generate various types of wastes after the buildings are completed. It is also considered that this type of working environment presents safety risks to construction workers on site. Thus, seen from Case I, the implementation level of hanging cradles is very high.

Furthermore, it can be seen from the case II that the implementation level of LWTs in the planning control stage tends to be high, while the level turns out to be relatively low in the construction process stage. This indicates that there is an urgent need for the construction participants to improve their regulation on the normative use of LWTs in the construction site. On the other hand, the implementation level may depend on the characteristics of the project. As for Case I, the implementation level of LWTs in both of the planning control and construction stages are quite high.

The interview discussions in this study show that there are various barriers to the application of LWTs in the Hong Kong construction industry. Using the semi-structured questionnaire designed for the interview discussion, the Likert scale is presented to the 15 key informants and it is used to help respondents present their opinions, which is commonly used for rating the relative significance of individual factors through examining experts' opinion [43,44]. The respondents were invited to judge the significance degree of each nominated barrier to the application of LWTs, with grade "1" as least significance, and "5" most. Finally, the ranking of then eight nominated barriers was identified on the basis of mean values of individual responses, as shown in Table 5.

Through the examination on the two cases, it appears that two barriers are considered as the top ones, which can be highlighted as follows:

6.1. Higher LWTs appliance design costs

Financial cost is considered as a critical barrier for contractors to decide whether to apply LWTs or not. In both of the cases investigated above, though extra cost had not been identified, contractors perceived that applying LWTs would be more expensive, thus affecting the level of application of the LWTs in these

Table 5
The relative significance of barriers in applying LWTs.

Barriers	Responses					Mean	Rank
	1	2	3	4	5		
Higher LWTs appliance design costs	0	0	0	7	8	4.533	1
Insufficient government support	0	0	5	5	5	4.000	2
Difficulty in implementing LWTs	0	1	6	7	1	3.533	3
Complicated planning and approval process	0	1	8	5	1	3.4	4
Lack of awareness to apply LWTs	0	2	7	6	0	3.267	5
Financial risks involved	0	2	8	5	0	3.200	6
Lack of experienced technician to implement LWTs	0	3	7	5	0	3.133	7
Interests conflicts among stakeholders	0	4	7	2	1	2.933	8

projects. This is echoed with Seydel et al., opined that the cost of applying advanced waste management technologies was generally perceived higher than that for traditional approaches [45]. Besides, the discussions in Case II comprehend that construction firms have paid more if they employ those LWTs (e.g. the recycling and reuse technologies and materials) than the traditional approach of dealing with construction waste such as to transport them to the landfills. In this context, they will have to pay extra cost to rent space to store the construction waste, the transportation fee, labor cost and administration fee. Consequently, the motivation for them to apply the LWTs is reduced.

6.2. Insufficient government support

Another challenge for the implementation of LWTs in Hong Kong is the insufficient government support. Although the Hong Kong government intends to improve the efficiency level of construction waste management, they fail to put adequate effort to enforce the implementation of regulations. For example, the key informants in the two cases recommended that the government should promote recycling market for construction wastes and build a systematic and uniform guideline for processing the construction waste. Not only it is effective to improving waste management by doing so, but also it can make local contractors know how they can deal with construction wastes under officially endorsed procedures in Hong Kong. Furthermore, it was revealed from the discussions that some project managers in construction sites were keen to introduce the LWTs, but had little power to do so because regulations and local policies do not provide those supports or legal advice. In this context, it is considered that the supervision guidance and commitments from the Hong Kong government can drive and motivate contractors to adopt LWTs. For example, by providing expedited permitting, mandate and grant policies, tax incentives, bonuses, and public recognition, the government can allow contractors to enjoy financial benefits and mitigate cost barriers in applying LWTs.

7. Conclusion

As the capacities of the current public fills and landfills in Hong Kong are decreasing, there is an urgent need for the promotion of low waste construction designs and technologies among the contractors to deal with both inert and non-inert construction waste generated in the process of construction. The research findings indicated that there are various LWTs available for implementation in developing construction projects across different stages, including planning and design, construction and operation & maintenance of buildings. Some of the commonly referred LWTs are identified and two of the LWTs in practice are highlighted, including 'large panel formwork' and 'the use of hanging cradles'. With the demonstration and comparison of the implementation level of the LWTs over two practical cases, two of the barriers for hindering the proactive implementation level of these LWTs are highlighted, including "higher LWTs appliance design costs" and "insufficient government support". This suggests that there is a need for policy and regulations on promoting the LWTs issues. In order to encourage contractors to be more considerate and proactive in waste management, more emphasis on the waste management plans and environmentally friendly policies when assessing their projects' environmental performance can be placed on. A set of design and technology toolkit for selecting appropriate LWTs for contractors and developers should be formulated in the construction industry in Hong Kong. Furthermore, there is also another urgent need to design legal framework to allow the growth of the market for recyclable and reuse construction materials in order to increase supplies and enable the contractors and developers to purchase more easily.

Further research is going to be undertaken to study the cost and benefits of the LWTs identified in this research, and to identify effective strategies to promote the high implementation level of their applications.

Acknowledgment

The authors appreciated the contributions from Prof. Geoffrey Qi Ping Shen, Department of Building and Real Estate, the Hong Kong Polytechnic University. We also appreciated the financial support from the Postdoctoral Fellowship Project Funding from the Hong Kong Polytechnic University with the title of "Green strategies of real estate developers in contributing to sustainable urbanization" (G-YX4W).

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